

WHAT IS CLAIMED IS:

1. A method for processing signals reflective of a monitored subject's respiration comprising:

filtering the respiratory signals to reduce signal components of non-respiratory origin, wherein the filtering adaptively responds to the behavioral state of the monitored subject, and

deriving a signal (V_t) indicative of lung volume from a combination of at least one filtered signal indicative of rib cage (RC) size and at least one signal indicative of abdominal size (AB).

2. The method of claim 20 wherein the behavioral state comprises at least one state selected from the group of lying supine, sitting, standing, walking, and running.

3. The method of claim 1 wherein a subject's behavioral state is indicated by signals from at least one accelerometer responsive to the subject's position and acceleration.

4. The method of claim 1 wherein the filtering adaptively responds in that at least two different filters are applied to the respiratory signals at different times, the applied filters being selected from a plurality of filters in dependence on a subject's behavioral state.

5. The method of claim 3 wherein the pass band of at least one filter applied when the behavioral state indicates decreased subject motion includes at least the pass band of at least one filter applied when the behavioral state indicates increased subject motion.

6. The method of claim 5 wherein the subject's motion is indicated by the power of all or a portion of at least one accelerometer signal from an accelerometer responsive to the subject's position and acceleration.

7. The method of claim 1 wherein the filtering adaptively responds in that motion artifacts in the filtered respiratory signals are reduced in moment-by-moment dependence on one or more further reference signals indicative of the subject's motion.

8. The method of claim 7 wherein the reference signals indicative of a subject's motion comprise a high pass filtered signal from at least one accelerometer responsive to the subject's position and acceleration.

9. The method of claim 1 wherein the filtering adaptively responds in that cardiac artifacts in the filtered respiratory signals are reduced in moment-by-moment dependence on one or more further reference signals indicative of the subject's cardiac activity.

10. The method of claim 10 wherein the reference signals indicative of a subject's cardiac activity motion comprise a signal derived from ECG input and/or from pulse oximeter input.

11. The method of claim 1 wherein the respiratory signals comprise respiratory plethysmographic signals.

12. The method of claim 1 wherein the respiratory signals comprise respiratory inductive plethysmographic signals.

13. A method for processing three or more independent signals reflective of a monitored subject's respiration comprising:

filtering the respiratory signals to reduce signal components of non-respiratory origin, and

deriving a signal (V_t) indicative of lung volume from a combination dependent on all three of more filtered signals.

14. The method of claim 13 wherein the combination dependent on the filtered signals comprises a linear model.

15. The method of claim 13 wherein the respiratory signals are sufficient to define changes in the shape of subject's torso, and wherein the combination comprises determining indicia of torso shape changes.

16. The method of claim 15 wherein the combination comprises constructing a model of torso shape.

17. A method for processing signals reflective of a monitored subject's respiration comprising:

filtering the respiratory signals to reduce signal components of non-respiratory origin, and

deriving a signal (V_t) indicative of lung volume from a linear combination of at least one filtered signal indicative of rib cage (RC) size and at least one signal indicative of abdominal size (AB),

wherein at least one coefficient of the linear combination is derived from a calibration procedure comprising

(i) selecting sets of inspiratory and/or expiratory volumes determined from the concurrent RC and AB signals,

(ii) performing a multi-step process to the selected sets of RC and/or AB volumes to detect and discard outlier values, and

(iii) deriving at least one coefficient from the sets of RC and AB volumes after discarding outlier values.

18. The method of claim 17 wherein the coefficient is derived as the ratio of the standard deviation (SD) of the set of RC volumes to the SD of the set of AB volumes, and/or the inverse of this ratio.

19. The method of claim 17 wherein the multi-step process comprises:

determining the standard deviation (SD) of an input set of lung volumes,

outputting a set of lung volumes from which lung volumes in the input set exceeding a pre-determined SD threshold have been discarded, and

repeating at least once the prior steps of determining and outputting, where the input set in a subsequent determining step is the output set of the previous providing step, and where the pre-determined SD thresholds are monotonically decreasing.

20. The method of claim 19 wherein the multi-step process comprises three determining and providing steps employing pre-determined SD thresholds of 3, 2, and 1, successively.

21. A method for processing signals reflective of a monitored subject's respiration comprising:

filtering the respiratory signals to reduce signal components of non-respiratory origin, and

deriving a signal (V_t) indicative of lung volume from a linear combination of at least one filtered signal indicative of rib cage (RC) size and at least one signal indicative of abdominal size (AB), wherein the linear combination adaptively responds to the behavioral state of the monitored subject.

22. The method of claim 21 wherein the behavioral state comprises at least one state selected from the group of lying supine, sitting, standing, walking, and running.

23. The method of claim 21 wherein a subject's behavioral state is indicated by signals from one or more accelerometers responsive to the subject's position and acceleration.

24. The method of claim 21 wherein the linear combination adaptively responds in that at least one coefficient of the linear combination is selected from a plurality of coefficients in dependence on a subject's behavioral state.

25. The method of claim 24 wherein the coefficient is selected from a plurality of coefficients in dependence on a position and/or posture indicated in subject's behavioral state.

26. The method of claim 25 wherein a position and/or posture indicated in subject's behavioral state is indicated by comparison of low pass filtered signals from two or more accelerometers responsive to the subject's position and acceleration.

27. The method of claim 24 wherein the coefficient selected for a particular behavioral state is derived from the calibration process applied to sets of inspiratory and/or expiratory volumes determined from the RC and AB signals selected to be representative of the particular behavioral state.

28. The method of claim 24 wherein the linear combination adaptively responds in that at least one coefficient of the linear combination is selected from a plurality of coefficients in dependence on motion indicated in a subject's behavioral state.

29. The method of claim 21 wherein the linear combination comprises a linear model that outputs the Vt signal in response to filtered RC and AB signal inputs and in moment-by-moment response to one of more further input signals indicative of a subject's behavioral state.

30. A method for processing at least one signal (Vt) reflective of a monitored subject's lung volume comprising:

deriving one of more temporal sequences of one or more respiratory parameters from the Vt signal,

recognizing artifacts by applying one or more rules to one or more of the sequences of respiratory parameters,

discarding those portions the sequences of respiratory parameters and corresponding portions of the Vt signal recognized to be artifacts.

31. The method of claim 30 wherein the Vt signal is derived from signals reflective of a monitored subject's respiration by a method comprising:

filtering the respiratory signals to reduce signal components of non-respiratory origin, and

deriving a signal (Vt) indicative of lung volume from a combination of at least one filtered signal indicative of rib cage (RC) size and at least one signal indicative of abdominal size (AB).

32. The method of claim 30 further comprising determining baselines for one or more sequences of respiratory parameters as moving median filtered values of the parameter sequences.

33. The method of claim 30 where the rules comprise recognizing as artifacts breaths with inspiratory and/or expiratory volumes less than a threshold factor times a fixed volume that is individually calibrated for the monitored subject.

34. The method of claim 30 wherein the rules comprise an outlier elimination rule.

35. The method of claim 34 wherein the outlier elimination rule recognizes as artifacts those values with deviations from the mean exceeding a factor times the standard deviation.

36. The method of claim 30 wherein the rules comprise a less than 25% rule.

37. The method of claim 36 wherein the 25% rule recognizes as artifacts those breaths with inspiratory and/or expiratory volumes less than a threshold.

38. The method of claim 30 wherein the rules comprise a true breath rule.

39. The method of claim 38 wherein the true breath rule recognizes as artifacts those breaths where the difference of the current end expiratory volume from previous end expiratory volume exceeds a threshold.

40. The method of claim 39 wherein the threshold comprises a threshold factor times a fixed volume that is individually calibrated for the monitored subject..

41. A method for recognizing respiratory events in a monitored subject's respiration comprising:

deriving a signal (V_t) indicative of lung volume from a plurality respiratory signals received from the monitored subject, and

deriving one or more temporal sequences of one or more respiratory parameters from the V_t signal, and

recognizing one or more respiratory events in dependence on at least one of the derived temporal sequences of respiratory parameters.

42. The method of claim 41 further comprising, subsequent to deriving temporal sequences, the steps of:

recognizing artifacts by applying one or more rules to one or more of the sequences of respiratory parameters, and

discarding those portions the sequences of respiratory parameters and corresponding portions of the Vt signal recognized to be artifacts.

43. The method of claim 41 wherein temporal sequences of inspiratory and/or expiratory volume parameters are derived from the Vt signal.

44. The method of claim 43 wherein periods of apnea are recognized dependence on these volume parameters being less than a threshold apneic volume, wherein the threshold apneic volumes varies in dependence on running median baseline lung volumes, and/or on the period, during which lung volumes were less than the threshold, being longer than a threshold apneic time,.

45. The method of claim 44 wherein apneic periods are classified in dependence on a phase relation between a signal reflective of rib cage size and a signal reflective of abdominal size.

46. The method of claim 43 wherein periods of hypopnea are recognized in dependence on these volume parameters being less than a threshold hypopneic volume but greater than a threshold apneic volume, wherein the threshold hypopneic and apneic volumes vary in dependence on running median baseline lung volumes, and/or on the period, during which lung volumes were between these thresholds, being longer than a threshold hypopneic time.

47. The method of claim 41 wherein a breath is recognized as a sigh if that breath is not an artifact according to the true breath rule, and has volume parameters greater than

a threshold sigh volume, wherein the threshold sigh volume varies in dependence on running median baseline lung volumes.

48. The method of claim 41 wherein temporal sequences of peak expiratory flow (PEF) parameters are derived from the Vt signal, and wherein a breath is recognized as a cough if that breath is not an artifact according to the true breath rule, and has a PEF greater than a threshold cough PEF, wherein the threshold cough PEF varies in dependence on running median baseline PEF.

49. The method of claim 41 wherein one or more breaths are recognized as comprising speech in dependence on one or more of the parameters inspiratory/expiratory (IE) ratio, the fractional inspiratory time, the inspiratory flow rate, or the expiratory time, wherein temporal sequences of each of these parameters are derived from the Vt signal.

50. The method of claim 41 wherein temporal sequences of minute ventilation volume and peak expiratory flow (PEF) parameters are derived from the Vt signal, and wherein dyspnea is recognized in dependence on a ratio of these parameters.

51. The method of claim 41 wherein temporal sequences of the time to reach peak expiratory flow and the expiratory time are derived from the Vt signal, and wherein changes in the ratio of forced expiratory volume in one second to vital capacity is recognized in dependence on a ratio of these parameters.

52. The method of claim 41 wherein temporal sequences of the peak inspiratory flow and the tidal volume are derived from the Vt signal, and wherein changes in the ratio of forced expiratory volume in one second to vital capacity is recognized in dependence on a ratio of these parameters.

53. The method of claim 41 wherein temporal sequences of the peak expiratory flow and the mean expiratory flow are derived from the Vt signal, and wherein changes in the ratio of forced expiratory volume in one second to vital capacity is recognized in dependence on a ratio of these parameters.

54. The method of claim 41 wherein a temporal sequence of the rib cage contribution to the tidal volume is derived from the V_t signal and a signal reflective of rib cage size, and wherein changes in the ratio of forced expiratory volume in one second to vital capacity is recognized in dependence on this parameter.

55. The method of claim 41 wherein a temporal sequence of the fraction of expiration time with thoraco-abdominal asynchrony is derived from a signal reflective of rib cage size and a signal reflective of abdominal size, and wherein changes in the ratio of forced expiratory volume in one second to vital capacity is recognized in dependence this parameter.

56. The method of claim 41 wherein temporal sequences of the peak inspiratory flow and the tidal volume are derived from the V_t signal, and wherein changes in the ratio of forced expiratory volume in one second to vital capacity is recognized in dependence on a ratio of these parameters.

57. A method for recognizing a cough in a monitored subject comprising:

recognizing a candidate sound event when an input level of a microphone signal exceeds a sound-event threshold, wherein the microphone is responsive to the subject's vocalizations,

filtering a lung volume signal (V_t) in dependence on characteristics of the candidate sound event,

recognizing a candidate respiratory event if the selected filtered tidal volume signal exhibits an expiration and a following inspiration having amplitudes greater than a amplitude threshold,

determining the occurrence of a cough if the candidate sound event coincides temporally with the candidate respiratory event.

58. The method of claim 57 wherein the sound-event threshold is a pre-determined multiple of a background noise intensity that is determined in the vicinity of the monitored subject.

59. The method of claim 58 wherein a candidate sound-event extends from the time when the input signal level exceeds the sound-event threshold to the time the time when the input level no longer exceeds the sound-event threshold.

60. The method of claim 57 wherein the amplitude threshold is individually calibrated for the monitored subject.

61. The method of claim 57 wherein the amplitude threshold is approximately 200 ml.

62. The method of claim 57 wherein the Vt signal is filtered into a lower frequency band (LFB) if the candidate sound event has a duration longer than a duration threshold, and into a higher frequency band (HFB) if the candidate sound event has a duration shorter than the duration threshold.

63. The method of claim 62 wherein the duration threshold is approximately 600 msec.

64. The method of claim 62 wherein the HFB excludes a range of low frequencies that are included in the LFB.

65. The method of claim 64 wherein the excluded range of frequencies is from approximately 0.4 to approximately 1.1 Hz, and wherein the frequency bands extend approximately 4.9 Hz.

66. The method of claim 57 wherein a cough is further determined only if the candidate respiratory event exhibits a sharp expiration, a minimum lung volume occurring during the central region of the associated sound event, and a sharp inspiration.

67. The method of claim 57 wherein a cough is further determined only if the candidate sound event has a pitch characteristic below a cough-pitch threshold.

68. The method of claim 67 wherein pitch characteristics are determined by short term spectral analysis of the input microphone signal.

69. The method of claim 68 wherein the short-term spectral analysis comprises determining mel-frequency cepsturm coefficients.

70. The method of claim 69 wherein the cough-pitch threshold is at met-frequency cepsturm coefficients of approximately 1.5-2.0.

71. A method for determining respiratory parameters capable of discriminating particular respiratory from base respiratory events comprising:

receiving respiratory signals from one or more monitored subjects such that the respiratory signals include one or more particular respiratory events and one or more base respiratory events, and

evaluating the capability of individual respiratory parameters and of combinations of respiratory parameters to statistically discriminate between the particular and the base respiratory events, and

selecting an individual respiratory parameter or a combination of respiratory parameters with adequate discriminatory capability.

72. The method of claim 71 wherein the step of evaluating comprises performs one or more linear statistical methods, including linear discriminant analysis.

73. The method of claim 71 wherein the step of evaluating comprises performs k-means clustering.

74. The method of claim 71 wherein a parameter or a combination of parameters has adequate discriminatory capability if either the false positive or false negative rate is 20% or less.

75. A method for processing signals reflective of a monitored subject's respiration comprising:

filtering the respiratory signals to reduce signal components of non-respiratory origin, wherein the filtering adaptively responds to the behavioral state of the monitored subject,

deriving a signal (V_t) indicative of lung volume from a combination of at least one filtered signal indicative of rib cage (RC) size and at least one signal indicative of abdominal size (AB),

wherein the linear combination adaptively responds to the behavioral state of the monitored subject, and

wherein at least one coefficient of the linear combination is derived from a calibration procedure comprising

(i) selecting sets of inspiratory and/or expiratory volumes determined from the concurrent RC and AB signals,

(ii) performing a multi-step process to the selected sets of RC and/or AB volumes to detect and discard outlier values, and

(iii) deriving at least one coefficient from the sets of RC and AB volumes after discarding outlier values.

deriving one or more temporal sequences of one or more respiratory parameters from the V_t signal,

recognizing artifacts by applying one or more rules to one or more of the sequences of respiratory parameters,

discarding those portions the sequences of respiratory parameters and corresponding portions of the V_t signal recognized to be artifacts, and

recognizing one or more respiratory events in dependence on at least one of the derived temporal sequences of respiratory parameters.

76. A computer system for processing signals reflective of a monitored subject's respiration comprising: a processor, and a memory in communication with the processor, the memory comprising encoded instructions for causing the processor to perform the methods of claim 75.

77. A program product for causing a computer system to process signals reflective of a monitored subject's respiration comprising a computer readable medium with encoded instructions for causing the system to perform the method of claim 75.

78. A computer system for processing signals reflective of a monitored subject's respiration comprising: a processor, and a memory in communication with the processor, the memory comprising encoded instructions for causing the processor to perform the methods of claim 55.

79. A program product for causing a computer system to process signals reflective of a monitored subject's respiration comprising a computer readable medium with encoded instructions for causing the system to perform the method of claim 55.